Short communication

Updating Class A pan coefficients (Kp) for estimating reference evapotranspiration (ETo) in the humid tropical region of Kerala

Celine George*

Centre for Water Resources Development and Management Sub centre, Manimalakunnu, Oliyappuram P.O., Koothattukulam 686 679, Kerala.

Received 26 July 2011; received in revised form 21 January 2012; accepted 22 January 2012.

Abstract

Evapotranspiration and evaporation are important parameters in water resource management and environment studies. This paper analyses six models for estimating pan coefficient (Kp) values in the humid tropical zone of Kerala. Estimated pan coefficients were not statistically accurate enough to be used for pan-to-ETo conversion. A significant increasing trend was observed for pan coefficient, whereas for evaporation and evapotranspiration, significant decreasing trends were observed over time. For the humid climate condition, the best Kp value for estimation of ETo is the constant value method and this constant value of Kp is to be updated for different climatic conditions.

Keywords: Evaporation, Penman-Monteith method, Pan coefficient.

Estimating evapotranspiration is important in water balance studies, water supply planning, and irrigation scheduling (Synder, 1992). There are many empirical methods available for estimating reference evapotranspiration (ETo). The globally accepted Modified Penmann-Monteith method, however, requires substantial weather data. Reliable estimates of ETo using pan evaporation (Epan) depends on the accurate determination of pan coefficients (Kp). For computing Kp values also several empirical models are available. In this study six such models were compared to find out the best one for the humid tropical region. Also an attempt was made to determine the trend in Kp values due to climate change.

Data on temperature, relative humidity, wind speed, sunshine hours, and evaporation collected from Centre for Water Resources Development and Management (CWRDM) station at Calicut (11°17’07” N and 75°52’15”E; 60 m altitude) for the period from 1986 to 2010 (25 years) were used. Monthly and yearly ETo values were computed using CROPWAT 8.0 software and Kp values estimated using the following six empirical models:

a) Doorenbos and Pruitt’s Table (Doorenbos and Pruitt, 1977)
b) Cuenca (1989): $Kp = 0.475 - 2.4 \times 10^{-4}U + 5.16 \times 10^{-3}H + 1.18 \times 10^{-3}F - 1.6 \times 10^{-5}H^2 - 1.01 \times 10^{-6}F^2 - 8.0 \times 10^{-9}H^2U - 1.0 \times 10^{-8}H^2F$ (1)
   where U = mean daily wind speed at 2 m height (km d^{-1}); H = mean daily relative humidity (%); and F = upwind fetch of low-growing vegetation equal to 20 m in this study.
c) Synder (1992): $Kp = 0.482 + 0.024 \ln(F) - 0.000376U + 0.0045H$ (2)
d) Raghuwanshi and Wallender (1998): $Kp = 0.5944 + 0.024X_1 - 0.0583X_2 - 0.1333X_3 - 0.2083X_4 + 0.0812X_5 + 0.1344X_6$ (3)
   where X_1 = ln of the fetch distance (F) in m; X_2, X_3 and X_4 = wind speed categories of 175–425,

*Author for correspondences: Phone 0485 2253517; Fax 04852253517; Email <celine@cwrdm.org>.

425–700, and >700 km d^{-1}, respectively, and were assigned values of one to zero depending upon their occurrence (zero for wind speed < 175 km d^{-1}); X_5 and X_6 = relative humidity categories of 40 to 70% and >79%, respectively (a zero value for these variables represent a relative humidity <40%).

e) FAO/56 (Allen et al.,1998): Kp = 0.108 – 0.0286U + 0.0422ln(F) + 0.1434ln(H) – 0.00063[ln(F)]^{2}ln(H) (4)

f) Constant Kp: this value was determined for CWRDM, Calicut by the relationship between ETo and Epan with the data from January 1986 to December 2010.

Kp obtained by the relationship between Epan and ETo computed using CROPWAT were compared with the Kp values computed using the six models. Epan observed were multiplied by the model-derived Kp values to get simulated ETo values. These simulated ETo values were compared with the computed ETo to evaluate model performance. To select the Kp models for providing the monthly ETo estimates, several performance criteria were used including the Nash-Sutcliffe coefficient of efficiency (N_{SE}) (Nash and Sutcliffe, 1970), relative error RE, and the Willmott index of agreement (Willmott, 1984). The N_{SE} ranges from – α to 1, with one indicating that the model is perfect. The N_{SE} was computed as shown in the equation:

$$N_{SE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right]$$

where Y_i^{obs} is the ith observation, Y_i^{sim} is the ith simulated value and Y^{mean} is the mean of observed data, for the constituent being evaluated and n is the total number of observations. RE is the ratio between the total difference and the total observed value (range: –1 to α). The smaller the absolute value of RE, the better performance of the model is. The index of agreement (*d*) developed by Willmott (1984) was used as a standardized measure of the degree of model prediction error (between 0 and 1). A computed value of 1 indicates a perfect agreement and 0 indicates no agreement between the measured and predicted values. The index of agreement can be calculated as shown in the following equation:

$$d = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(\left|Y_i^{sim} - Y^{mean}\right| + \left|Y_i^{obs} - Y^{mean}\right|\right)^2} \right]$$

Temporal trends in Kp, ETo and Epan values were estimated using the MAKESENS (Mann Kendall test for trend and Sens's slope estimates) excel template (Timo, 2002).

The empirical equations did not predict Kp values very well (r= < 0.25, Fig.1). But the ETo computed using these Kp values showed reasonable agreement (Fig.1). The constant value method showed a high degree of agreement and had low relative error. But the N_{SE} value was very less showing poor predictive

Table 1. Performance evaluation of computed and simulated ETo values for the humid tropical region of Kerala.

Kp Method	d	N_{SE}	RE (%)
Doorenbos & Pruitt table	0.74	– 0.587	20.2
Cuenca	0.75	– 0.428	18.9
Synder	0.86	0.26	10.0
Raghuwanshi & Wallender	0.73	– 1.453	20.5
FAO/56	0.64	– 1.336	26.1
Kp=1.0	0.89	0.312	0.20

d = degree of agreement, N_{SE} = Nash Sutcliffe coefficient, RE = relative error

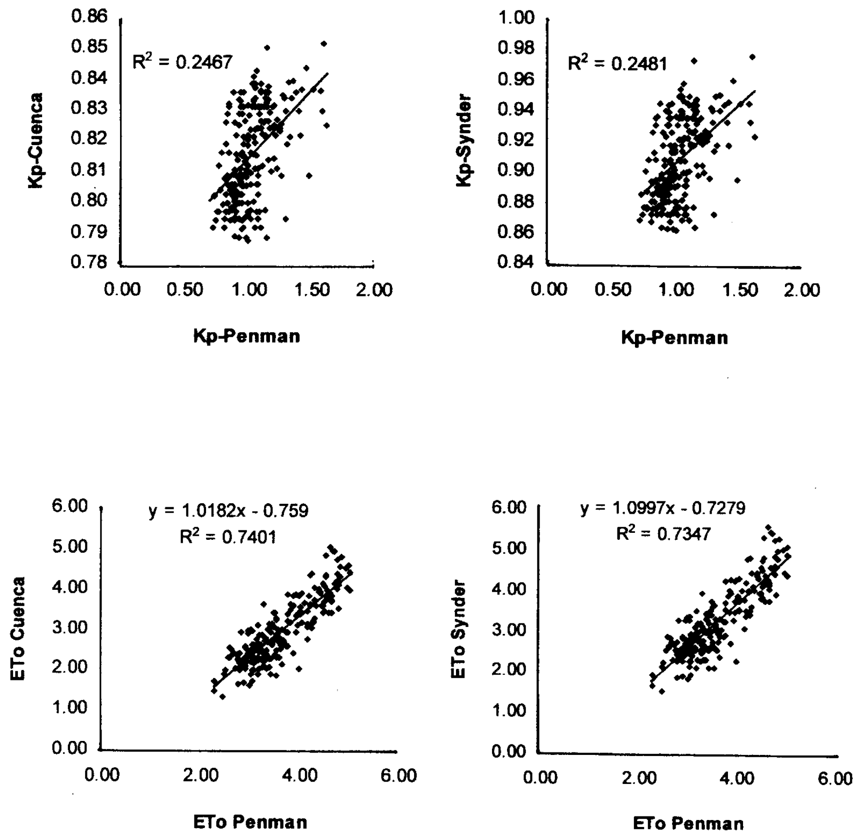

Figure 1. Relationship between monthly Kp values and monthly ETo values computed by Penman-Monteith equation and estimated by Cuenca and Synder models for the humid tropical region of Kerala.

power. Using a fixed value is a simple and practical option to convert Epan to ETo, without the need for weather data. However, this value must be calibrated and updated for each place under different climatic conditions. Statistically decreasing trends (Table 2) for pan evaporation at 0.01 probability and evapotranspiration at 0.05 were noted. An increasing trend (Fig. 2) was observed for pan coefficient at 0.05 significance level, which explains the necessity of updating Kp value. Bottom line is that:

- Determination of Kp values by the empirical models used in this study did not fit with the values calculated using Modified Penman-Monteith equation.
- Use of a constant value of Kp is a simple and

Table 2. Trend statistics for Kp, ETo and Epan for the humid tropical region of Kerala.

Time series	First year	Last year	n	Test Z	Signific.
Kp	1986	2010	25	2.325	*
ETo	1986	2010	25	–2.446	*
Epan	1986	2010	25	–3.956	***

n = total number of years, Kp = pan coefficient, ETo = evapotranspiration, Epan = pan evaporation,
* significance level (0.05), *** significance level (0.001)

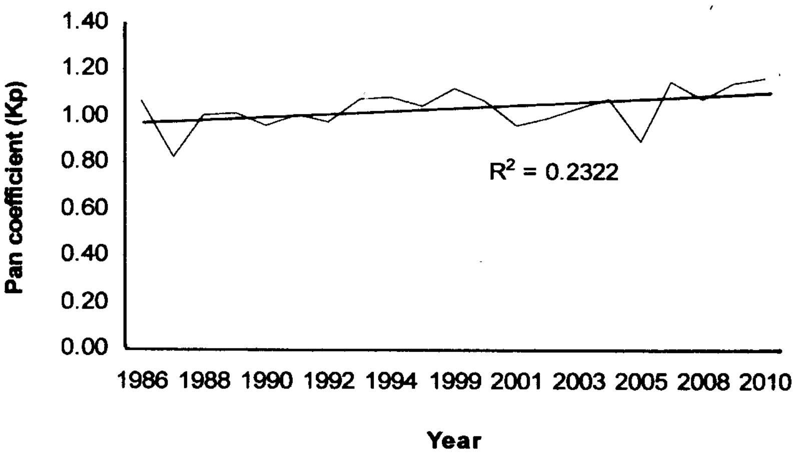

Figure 2. Statistical trend of pan oefficient for the humid tropical region of Kerala.

practical option to convert Epan to ETo, however, this value must be calibrated and updated for different climatic conditions.

- An increasing trend was observed for Kp and decreasing trends were observed for ETo and Epan in the humid tropical region over time, implying the need to consider the changing weather patterns in arriving at the optimal values of Kp.
- The trend detection study clearly indicated the need for updating Kp values.

Acknowledgements

The Executive Director of CWRDM, Prof. (Dr.) KV Jayakumar and the Head of Sub Centre, Dr MD Nandeshwar have been kind enough to provide all the infrastructure facilities to carry out the study. Their timely guidance and motivation are gratefully acknowledged. I extend my sincere thanks to Dr. EJ Joseph, Head, Water Management (Agri) division, CWRDM for supplying the climatological data.

References

Allen, R.G., Pereira, L.S., Dirk, R., and Smith, M., 1998. Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome. 86p.

Doorenbos, J., and Pruitt, W.O.,1989, Crop water requirement, Rome: Prentice-Hall, Englewood Cliffs, New Jersey,133p.

Nash, J.E., and Sutcliffe, J.V. 1970. River flow forecast-ing through conceptual models: Part I. A discussion of prin-ciples. J. Hydrol., 10(3):282– 290.

Synder, R.I. 1992. Equation for evaporation pan to evapotranspiration conversion. J. Irrig. Drain., 118: 977– 980.

Timo S., Maatta, A., Anttila, P., Ruoho-Airola, T. and Amnell, T. 2002. Publications on Air Quality No.31, Report code FMI-AQ-31, Finnish Meteorological Institute, Vuorikatu 24, Finland, pp 12– 20.

Willmott, C.J. 1984. On the evaluation of model perfor-mance in physical geography. In Spatial Statistics and Models. Gaile G.L. and Willmott C.J. (ed.), D. Reidel. Norwell, MA, pp. 443– 460.